EFFECTS OF ATOMIC EXPLOSIONS ON THE FREQUENCY OF TORNADOES IN THE UNITED STATES[1]

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ABSTRACT

The upward trend in reported tornadoes during the past few years has led many people to suspect that atomic explosions are responsible for the increase. Because there is no known physical reason for believing that atomic explosions should affect the tornado frequency, the records of tornadoes and atomic explosions are examined in considerable detail to find evidence which will support or contradict this popular hypothesis.

It is found that tornado reports have always been incomplete and that much of the recent upward trend in tornado frequency can be accounted for by improvements in the tornado reporting system. A comparison of the distribution of tornadoes and of debris from an atomic explosion in time and space does not support the hypothesis that atomic explosions tend to increase the tornado frequency.

INTRODUCTION

The 532 tornadoes reported in the United States in 1953 exceeded the next highest yearly total of record by more than 200. Of the 532 tornadoes, 294 were reported between March 17 and June 15, the period when atomic weapons were being tested in Nevada. The coincidence of this increase in the number of reported tornadoes with the increase in the frequency of atomic explosions in 1953 led many people to believe that atomic explosions caused an increase in tornadoes.

Because of its importance to the success of atomic tests and to the transport of the radioactive debris, the weather during periods of atomic tests has been studied in considerable detail (Cumberledge [1], Holzman [2], and List [3]). Any obvious effects of the explosions on weather should have been revealed by these studies, but no evidence of any effect away from the test site was found.

Machta and Harris [4] have investigated the possibility that the debris from atomic explosions might provide ice nuclei in regions having a natural deficiency, and thereby affect the rainfall regime for a short time after each atomic explosion; that the debris might interfere with the amount of solar radiation reaching the earth, and thereby change the temperature at the ground; or that the radioactivity of the debris might change the electrical properties of the atmosphere, and that this in turn might lead to some changes in the more observable weather. They found that none of these possibilities was likely to occur to any significant extent. They were unable to find any theory which is consistent with the known facts that would indicate that atomic explosions could alter the natural occurrence of tornadoes.

[1] Paper presented at 133d National Meeting of the American Meteorological Society Miami, Fla., November 17-19, 1954.

Since the true cause of tornadoes has not been firmly established, the failure of any of these theories to relate tornado occurrence to atomic explosions, is not in itself conclusive. However, an examination of the available observational data should show whether there is any reliable evidence of a relation between atomic explosions and tornado occurrence.

TORNADO RECORDS

The number of tornadoes reported to the Weather Bureau during the period 1916 through 1953 is shown by the bars in figure 1. The solid line shows the linear trend of these reports based on data for the years 1921–50. The dashed line shows the rate of population growth as determined from the last four census reports. The correlation between these two lines suggests that the linear trend prior to 1950 may be due to factors which are closely related to population, but some other factor must be found to explain the increase since 1950. In order to find this, we must examine the method of collecting tornado statistics.

Tornadoes are occasionally observed by Weather Bureau observers. More often, the first report of any tornado or suspected tornado comes from the public. Sometimes the first report is found in a newspaper account of the storm. Each reported tornado is investigated by a meteorologist, in person if possible, but it is often necessary to rely on detailed reports by laymen who live in the vicinity of the reported storm. These investigations sometimes disclose sufficient information to permit definite identification of the storm as a tornado, or to show that the initial report was in error in calling the storm a tornado. More often the data are inconclusive, and it is unlikely that all meteorologists engaging in the

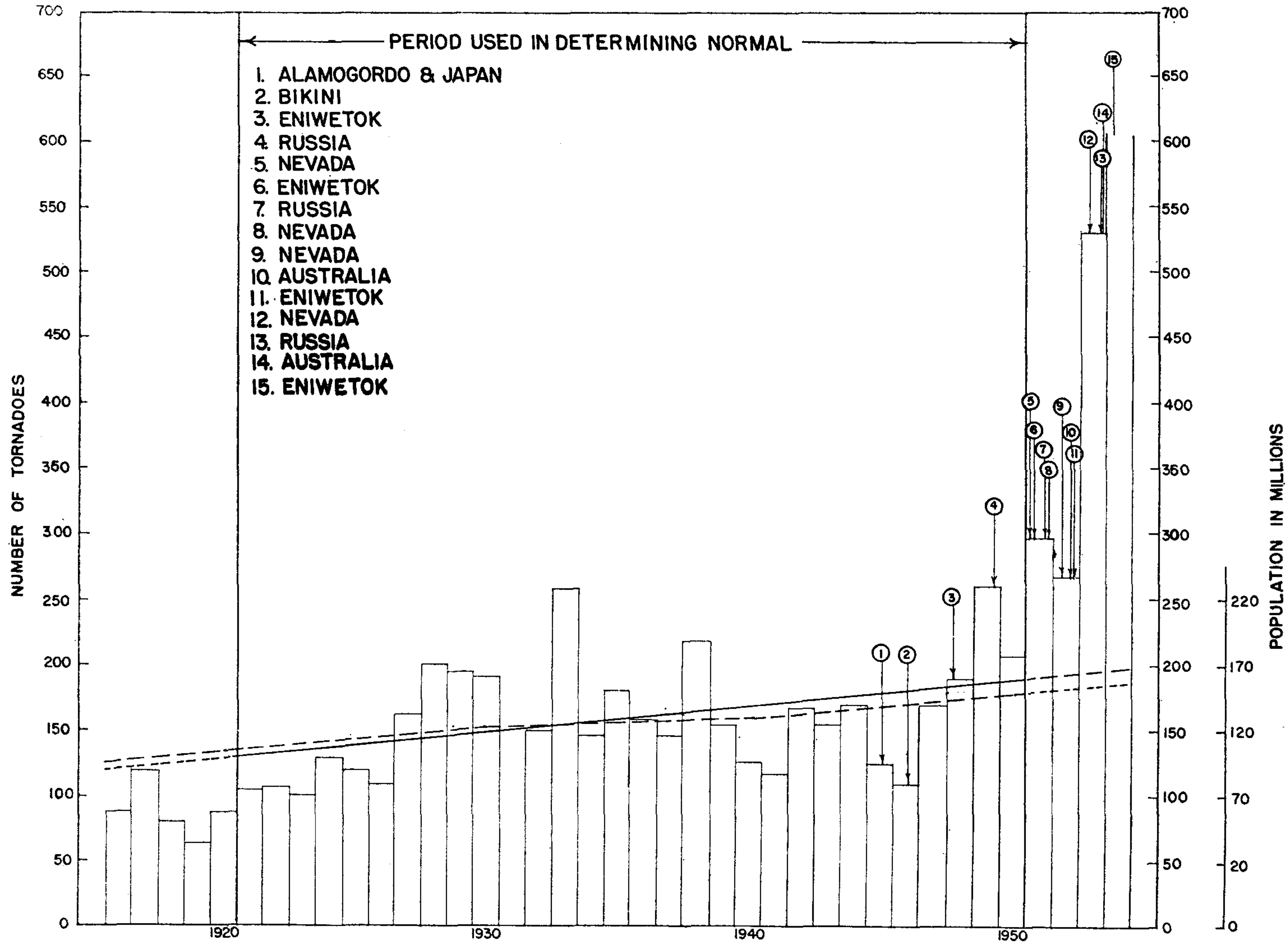

FIGURE 1.—Annual tornado frequency 1916–53, and dates of atomic explosions. Solid line shows trend based on data for 1921–50. Dashed line shows rate of population growth.

study of tornadoes would agree on the classification of every storm. However, no storm can be investigated much less classified, unless a report of it reaches the Weather Bureau and thus the first requirement that any storm must satisfy before it can be classified as a tornado and appear in the statistics, is that it be reported to the Weather Bureau. It is unlikely that all tornadoes are reported, and it appears probable that the percentage of tornadoes reported is greater in regions of high population density, and that it increases with the population and with the effort spent to obtain complete reports.

EFFECTS OF POPULATION DENSITY

The hypothesis that the percentage of tornadoes reported is a function of population density is difficult to check because the meteorological conditions which favor the formation of tornadoes are not equally common over any large region. However, if we select a small area of high population, say a county, and surround this with a group of counties with low population density, the meteorological conditions should be about the same in both regions, so that any observed difference in reported tornado frequency will be due to chance occurrences or to the population differences. The population and tornado statistics [2] have been examined in this way for six States in the tornado belt, Nebraska, Kansas, Oklahoma, Iowa, Missouri, and Arkansas. In figure 2, the 28 counties or groups of counties of these six States having a population of 50 persons or more per square mile in 1940 are shaded. The outlined unshaded areas denote the surrounding counties with lower population densities. The average tornado density for the period 1921–50 is higher in the high-population areas in 22 of the 28 regions. A summary of these data is given in table 1.

The mean difference in the tornado densities in these two types of area for the period 1921–50 is 0.084, and the

[2] All tornado statistics are taken from the official records of the Weather Bureau. These have been published in the *Climatological Data, National Summary* since 1950. Before 1950, they were published in the *Monthly Weather Review*, or the *Meteorological Yearbook*. Many of these statistics are summarized in *Technical Paper* No. 20, "Tornado Occurrences in the United States", U. S. Weather Bureau, September 1952.

TABLE 1.—*Average tornado density per 1,000 square miles per year as a function of population density*

	1921–50	1951	1952	1953
Counties with more than 50 persons per square mile	0.304	0.234	0.466	0.633
Counties with less than 50 persons per square mile	.220	.169	.267	.645

standard deviation of this mean is 0.041. The probability of obtaining a difference of this amount, when no true difference exists, is only about 0.04. Since there is no theoretical reason for expecting a correlation between tornado occurrences and population density, the true cause of the difference is probably the completeness or incompleteness with which tornadoes are reported in the two types of area. Since the population is not evenly distributed throughout the high-population counties, it is also probable that even here tornadoes have occurred which were not reported.

The data for 1951 and 1952 are also biased in the direction of greater tornado density in the high-population regions. In the data for 1953, this bias disappears, suggesting that the reporting of tornadoes in rural areas may have caught up with that in urban areas. However, the tornado density was higher in the low-population areas in 9 of the 30 base years, and the results for a single year cannot be regarded as significant.

EFFECTS OF INCREASED EFFORT TO OBTAIN REPORTS

During World War II, at the request of defense officials, the Weather Bureau organized a large number of severe local storm warning networks around military bases and ordnance plants. Most of these were discontinued shortly after the end of the war. However a few, in the most storm conscious areas of the country remained active from the time they were first established.

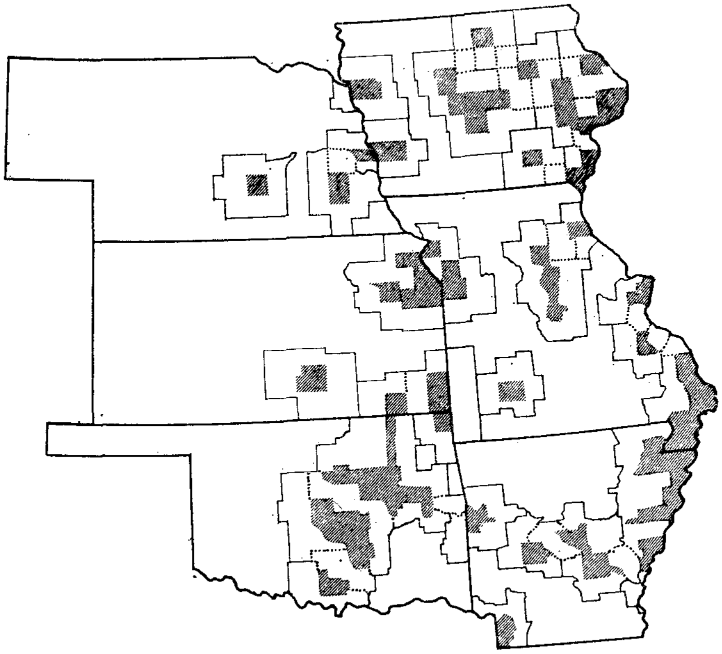

FIGURE 2.—Population density, 1940. Shading indicates a county with population of greater than 50 persons per square mile.

In 1949, the Weather Bureau began to reactivate some of these networks and to establish others around Weather Bureau offices, especially those east of the Rockies. State and county law enforcement officers, and many other organizations such as the Red Cross and public utility companies, as well as many private citizens were asked to report certain information concerning any severe local storms that came to their attention. The number of these networks was increased from 11 in January 1949 to over 100 in January 1953, and 170 in January 1954.

In 1953 and 1954, the Weather Bureau cooperated with Federal Civil Defense Officials and civic organizations in establishing community reporting and warning networks for protection from fast moving storms such as tornadoes. Several hundred such networks have been established, and all tornadoes detected by them are reported to the Weather Bureau.

Developments in tornado research since 1950 have led to a need for an even greater improvement in the completeness of tornado reports. In 1951, contracts were negotiated with private press-clipping services to increase the completeness of tornado reports received by the Weather Bureau. This policy has been continued and extended since 1951. Tepper [5] has described the workings of the clipping service in 1951, and only a summary will be given here.

TABLE 2.—*1951 monthly and annual frequency of tornado reports for the entire United States and for the Kansas-Oklahoma area, after Tepper [5]*

	United States			Kansas-Oklahoma			United States less Kansas-Oklahoma		
	Reported in newspapers	Official record	35-year mean	Reported in newspapers	Official record	35-year mean	Reported in newspapers	Official record	35-year mean
Jan.	3	3	4	0	0	<1	3	3	4
Feb.	19	10	5	6	6	<1	13	4	5
Mar.	12	9	17	4	4	2	8	7	15
Apr.	39	27	24	27	19	5	12	22	19
May	86	76	33	64	55	9	22	21	24
June	125	90	26	77	51	6	48	39	20
July	32	25	12	9	6	2	23	19	10
Aug.	35	29	8	20	14	1	15	15	7
Sept.	9	9	7	2	2	1	7	7	6
Oct.	3	3	4	1	1	1	2	2	3
Nov.	12	12	5	0	0	<1	11	12	5
Dec.	11	11	3	0	0	<1	11	11	3
Annual	386	300	149	210	158	28	176	142	120
4-month total	278	220	79	170	126	18	108	94	61

The clipping service was in effect from late April through August 1951 for the States of Kansas and Oklahoma in the region of maximum tornado frequency. The efficiency of this service is indicated by table 2 (from [5]). It is seen that in Kansas and Oklahoma the number of storms officially designated tornadoes during the 4-month period,

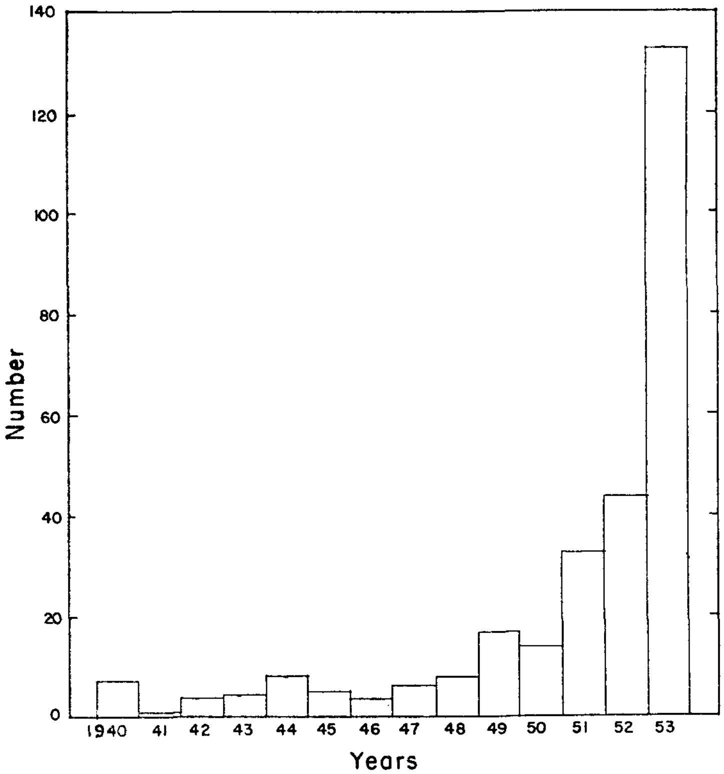

FIGURE 3.—Number of reports of tornado funnels not reaching the ground.

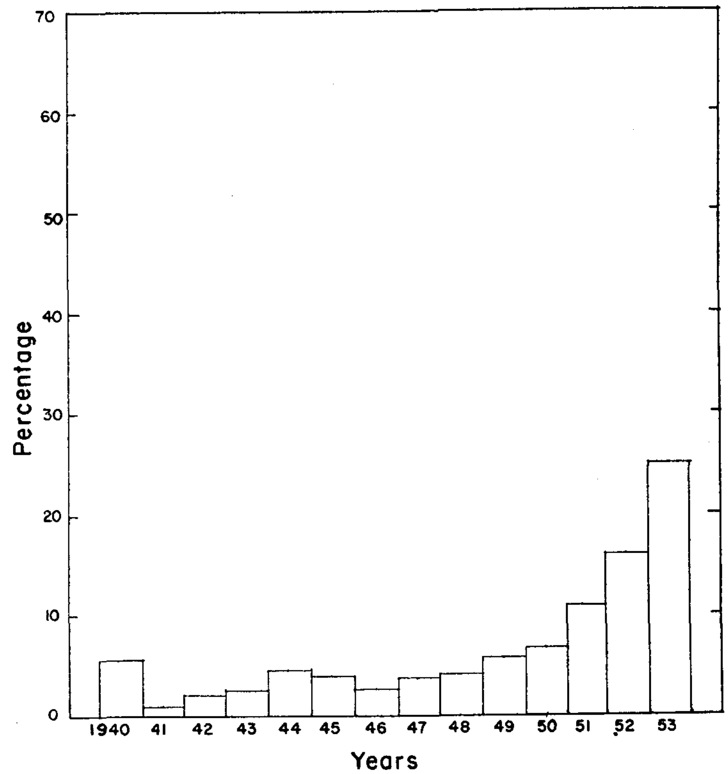

FIGURE 4.—Percent of reported tornadoes not reaching the ground.

May–August, was 126 compared to a 35-year average of 18. The number for the remainder of the country was 94 compared to a 35-year average of 61. This amounts to an increase of 600 percent in the area covered by the clipping service as compared to an increase of only 54 percent in the rest of the country, for the period the clipping service was in full operation. No other State having as many as 10 tornadoes during the year showed an increase comparable to that of Kansas and Oklahoma.

In 1952, the clipping service covered the same area for the period March through August. This time the number of tornadoes reported in Kansas and Oklahoma was 54, or an increase of 116 percent over the 35-year average. The number reported in the remainder of the country was 160 or an increase of 78 percent over the long-term average.

In 1953, the clipping service was extended to the 11 States within the heavy outline in figures 11 and 12 and was effective from February through August. Of the tornadoes in the United States in 1953, 86 percent occurred during this period so a satisfactory comparison can be made by considering only the annual totals. There were 292 tornadoes reported in the area covered by the clipping service compared to the 35-year average of 54. This amounts to an increase of 440 percent. There were 240 reported in the 37 States not covered by the clipping service. The 35-year average is 91, so that this increase is only 160 percent.

In 1954, the clipping service was extended to all of the United States east of the Rocky Mountains and a comparison between the rate of increase in the States covered and in the rest of the United States becomes meaningless.

The effect of the newspaper clipping service in increasint the total number of tornadoes reported to the Weather Bureau is obvious. However, this may not explain all of the increase. The advances made in tornado forecasting, in tornado research, and the publication of a great many popular articles concerning tornadoes since 1950, as well as the severe local storm warning networks mentioned above, have led to a greater interest in tornadoes among many segments of the public and this has led to an increase, difficult to evaluate, in the number of tornadoes that are reported directly to the Weather Bureau or to newspapers. One significant change in the character of tornado reports in recent years is in the number of reports of tornado funnels not reaching the ground. This is shown in figure 3. The rate of increase of tornado reports of this class (fig. 4) is much greater than the rate of increase of tornadoes doing heavy damage, and is believed to be an indication of the increased interest in tornado reporting, for it requires a greater interest in the subject to report a tornado of this class, than to report a damaging tornado.

The possibility of an actual increase in the number of tornadoes cannot be neglected. The synoptic weather patterns during the tornado season in 1953 were similar to 1933, the year with the maximum number of tornadoes before 1951, and it appears likely that 1953 would have been an unusual tornado year by any system of counting.

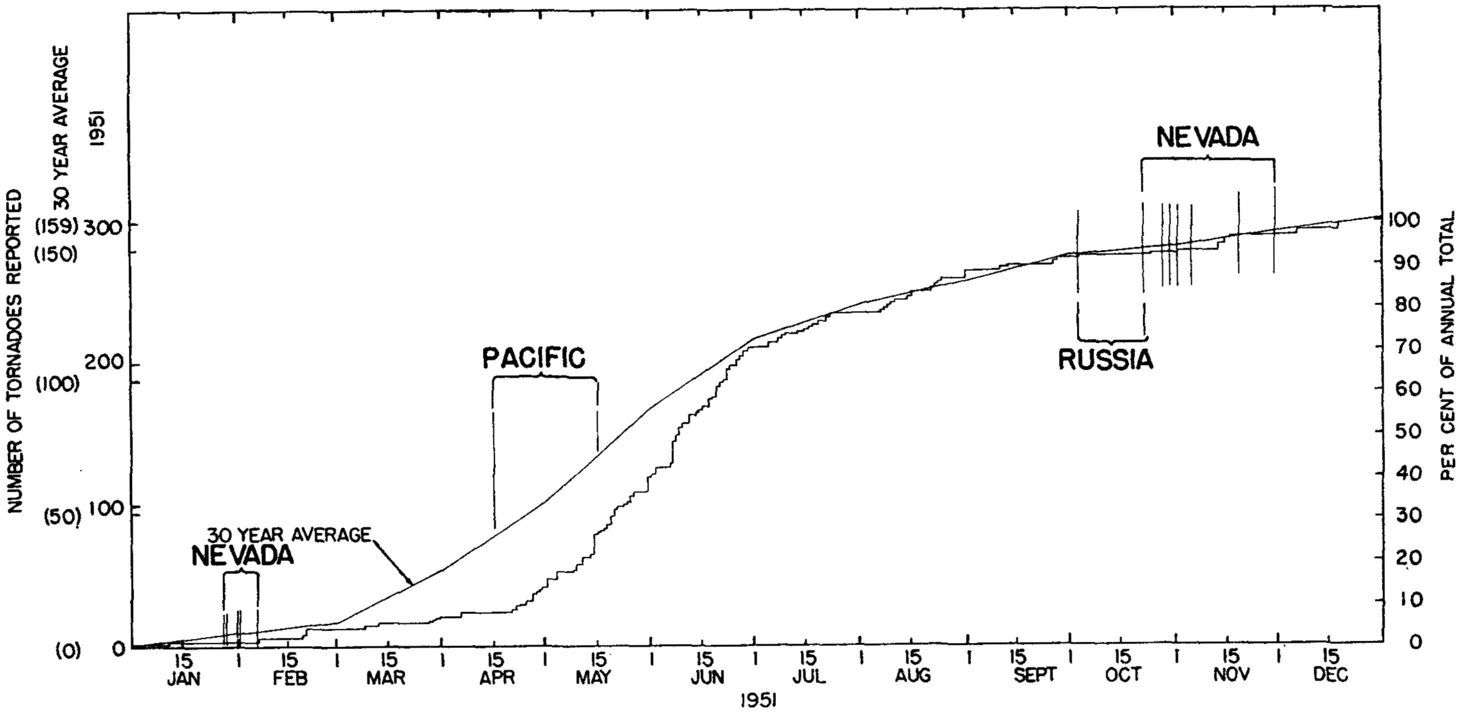

FIGURE 5.—Distribution of tornadoes and atomic explosions, 1951 and comparison with 30-year seasonal average.

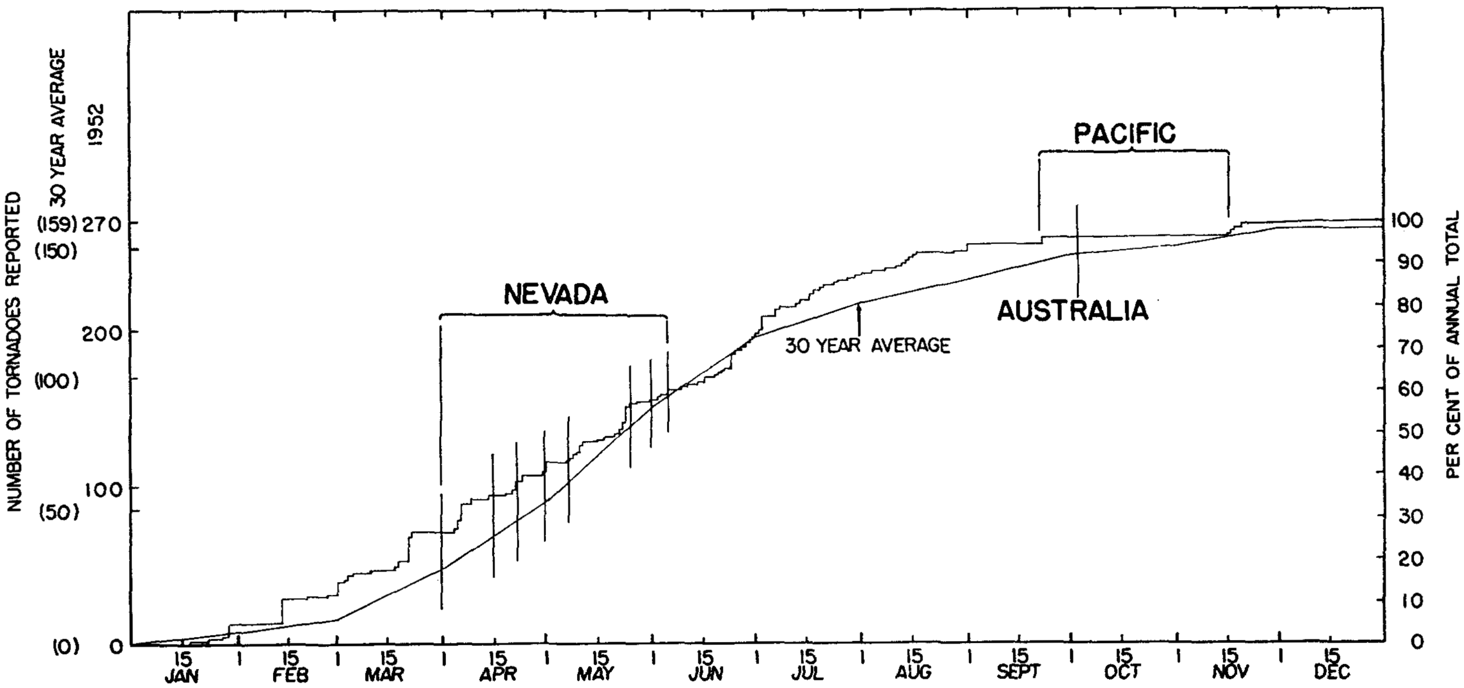

FIGURE 6.—Distribution of tornadoes and atomic explosions, 1952.

Although more tornadoes were reported in 1954 than in 1953, there appears to be little reason for believing that 1954 was an exceptionally favorable year for tornadoes.

It is clearly established that tornado statistics were incomplete, at least before 1954, and that improvements in the methods of collecting tornado reports have been responsible for much of the increase in the totals reported since 1950. This improvement has been so great that it cannot be determined from an inspection of the tornado records, whether or not there has been any increase in the actual occurrence of tornadoes.

CORRELATION BETWEEN DATES OF ATOMIC EXPLOSIONS AND TORNADO OCCURRENCES

To study the possible correlation between atomic explosions and tornadoes, it is necessary to consider

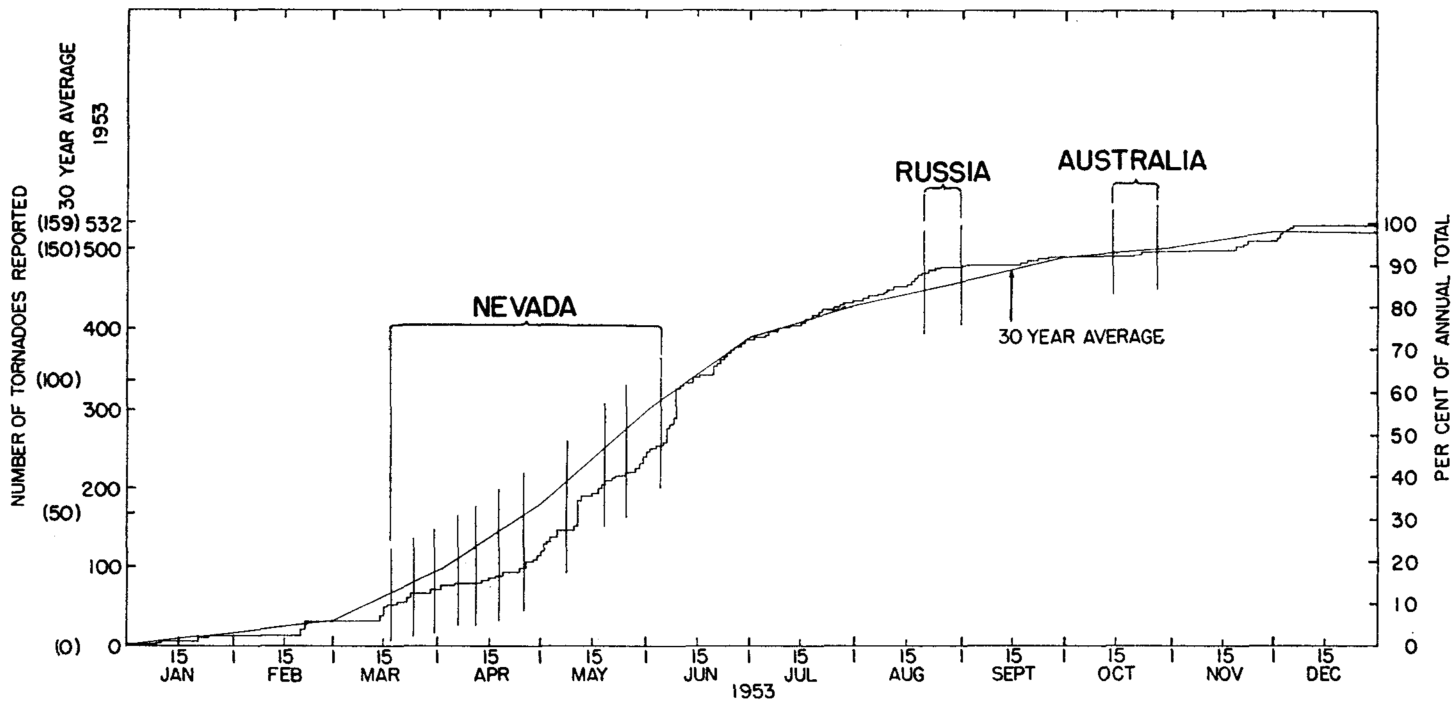

FIGURE 7.—Distribution of tornadoes and atomic explosions, 1953.

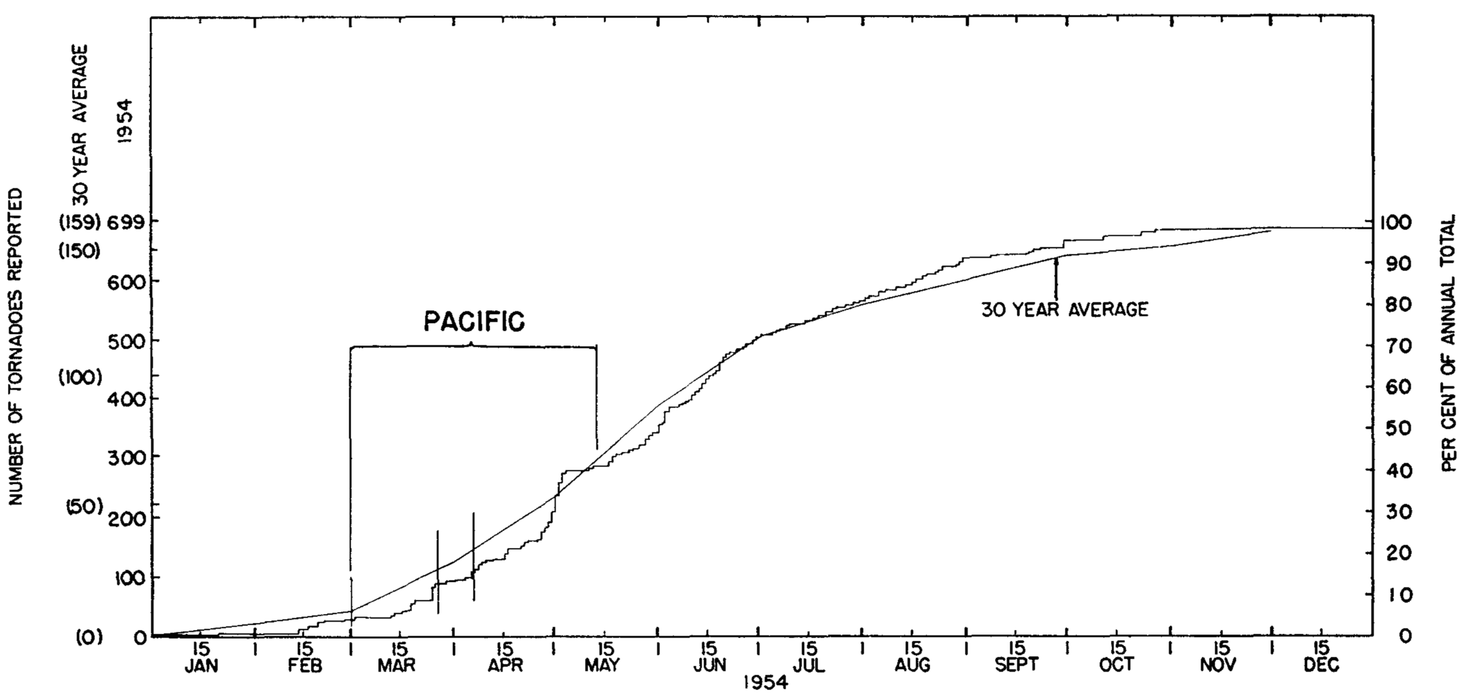

FIGURE 8.—Distribution of tornadoes and atomic explosions, 1954.

the distribution of both tornadoes and atomic debris in time and space. It will be recalled from figure 1 that in 1945, the year in which the first atomic bombs were exploded, the number of tornadoes reported in the United States was well below normal. The second group of atomic explosions, this time in the Pacific, was conducted in 1946, and this year also was below normal in reported tornadoes. Both the intense program of atomic weapons testing in the United States and the rapid increase of tornado reports began in 1951. Therefore, only the last four years have been studied in detail.

Although the total number of tornadoes reported has increased in recent years, due to increased emphasis on obtaining complete reports, this does not preclude the possibility that the atomic bombs may have had some influence on the development of tornadoes. In order to

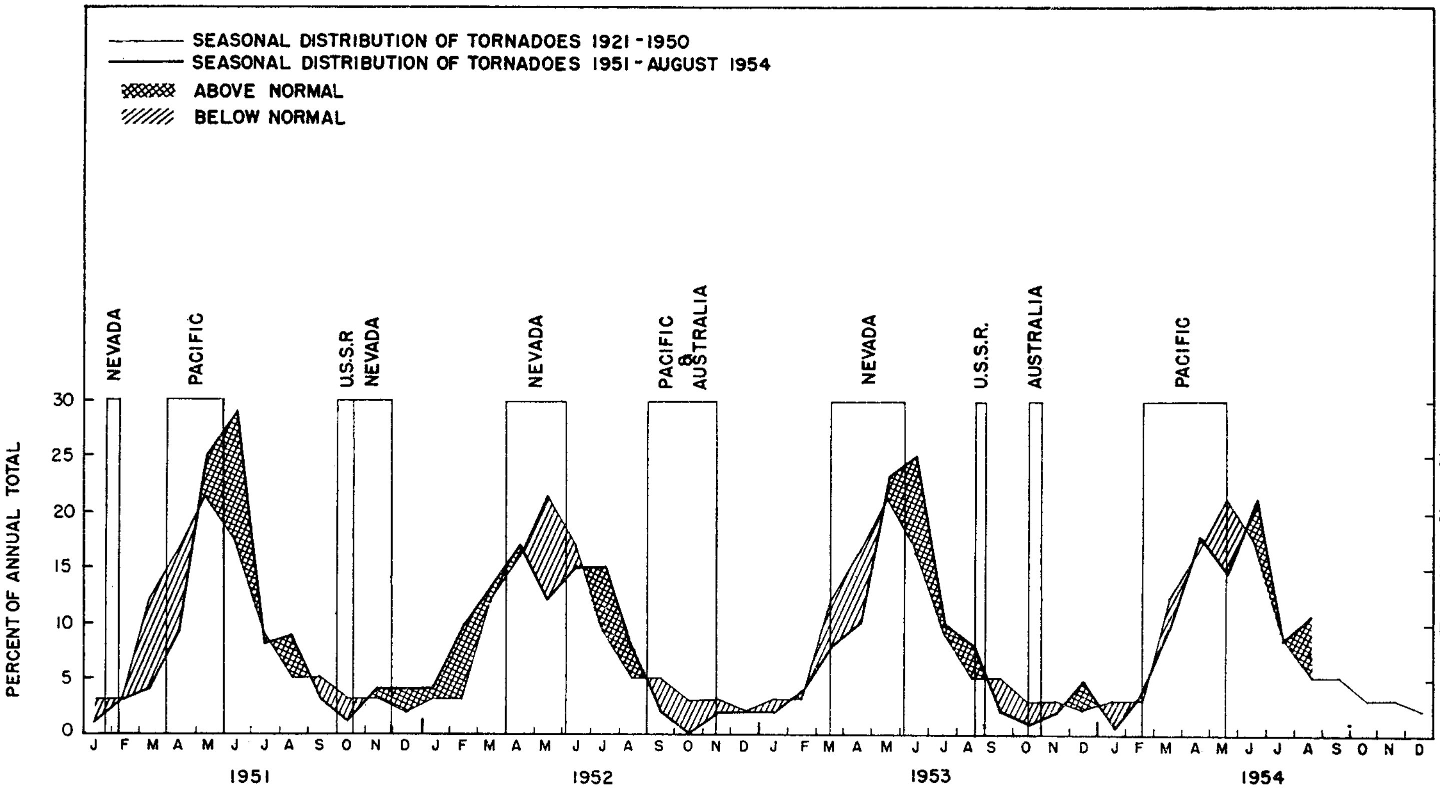

FIGURE 9.—Seasonal distribution of tornadoes, 1951–54, compared to normal distribution and to atomic test periods.

investigate this possibility, it is necessary to form a hypothesis concerning the manner in which this influence might be exerted. Since no evidence has been found of any large-scale effect of atomic explosions on weather, it will be assumed that the influence, if any, must be confined to the time of the explosion, or to the location of the radioactive cloud. The amount of radioactivity from an atomic explosion decreases rapidly with time, and much of the debris is brought to the earth within a few days after the explosion, therefore, any effect due to the debris must decrease rapidly with time.

If atomic explosions have encouraged the formation of tornadoes, it is to be expected that the seasonal distribution will have been altered in the direction of relatively more tornadoes during and for a while after the period of the atomic tests than at other times. The trend toward more complete tornado reporting was more or less continuous between 1920–50 and there is little reason for believing that the reporting system was improved more in one month than in another. Thus, it is reasonable to assume that the relative seasonal distribution of tornadoes is better known than the total number that occur in any particular year. The data for 1921–50 have been used to determine a 30-year average ("normal seasonal distribution") of tornadoes.

Figures 5–8 show plots of the daily accumulated tornado reports for the years 1951–54. In order to make the reports for these later years comparable with the earlier years when the reporting system was less efficient, the scale on the right shows percent of the annual total; the actual number of tornadoes is given by the left hand scale. The "normal" distribution is given by the dashed line. The actual numbers for the "normal" distribution are given on the left hand margin in parentheses. The dates of all atomic explosions in the United States, and of all announced atomic explosions elsewhere are indicated on these graphs. In 1951 (fig. 5), the test periods in the United States were in January, February, October, and November, outside of the usual tornado season, and there is no indication that any of these explosions were associated with tornadoes. The Pacific tests were in April and May and the fraction of the annual total occurring during this period was below normal.

In 1952 (fig. 6), the first period of intensified tornadic activity occurred before the first atomic explosion, and, in general, an outbreak of tornadoes preceded rather than followed an atomic explosion. This certainly does not indicate a possible cause and effect relation. Again in 1953 (fig. 7), the first two groups of tornadoes occurred before the first atomic explosion, and the tendency toward a record year was established before the atomic test program was begun. There is some evidence of an increase in the tornado frequency a few days after some of the atomic tests in 1953. However, in view of the large number of tornado groups and the large number of atomic explosions in the spring of 1952 and 1953, this coincidence does not appear to be more than one might expect by chance. Once again in 1954 (fig. 8), the first group of tornadoes occurred before the first atomic explosion. None of the steep regions on this curve correspond to a

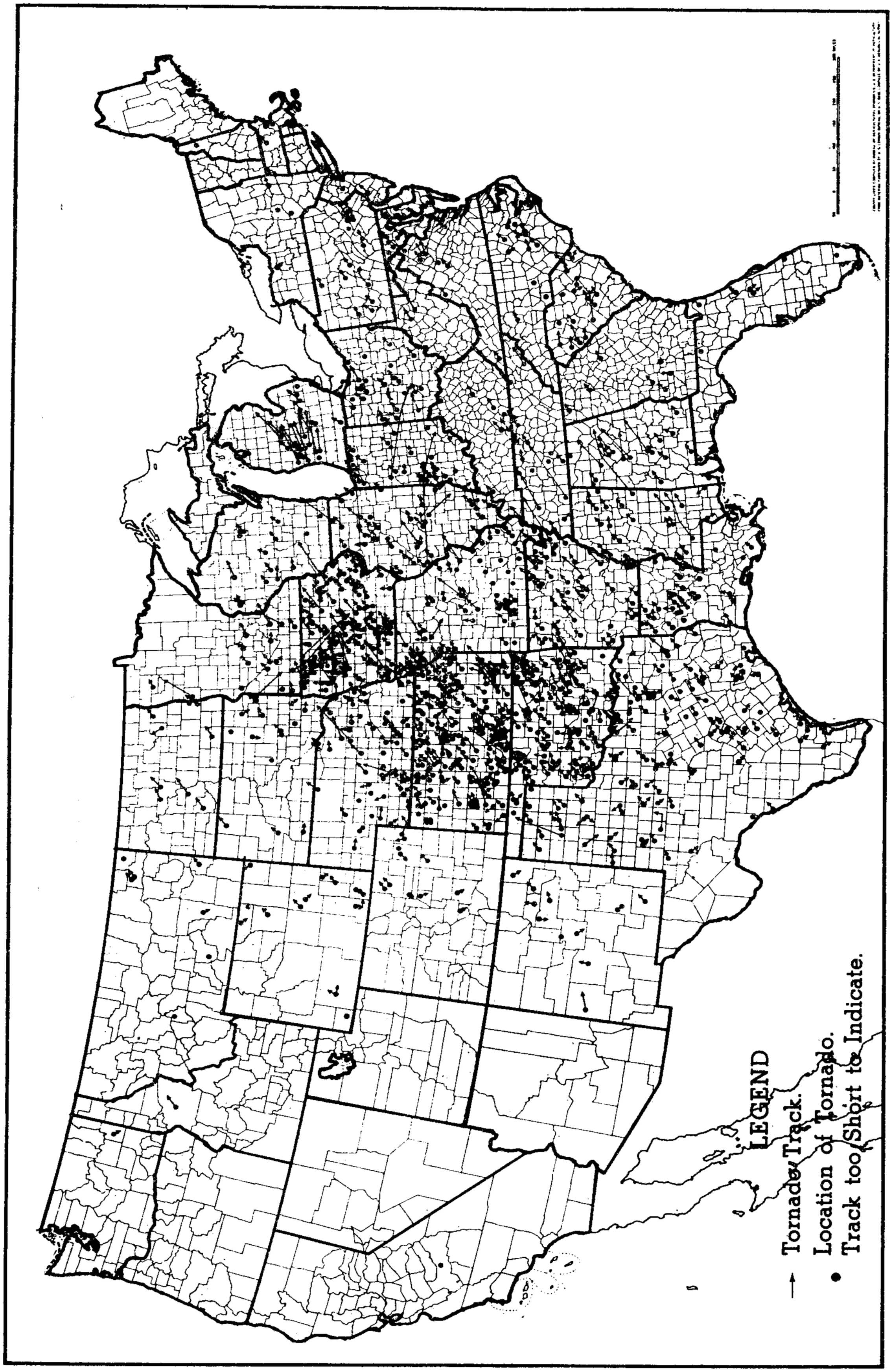

FIGURE 10.—Tornado tracks for all Mays, 1916–50. (From Weather Bureau *Technical Paper* No. 20, "Tornado Occurrences in the United States," Washington, D. C., 1952.)

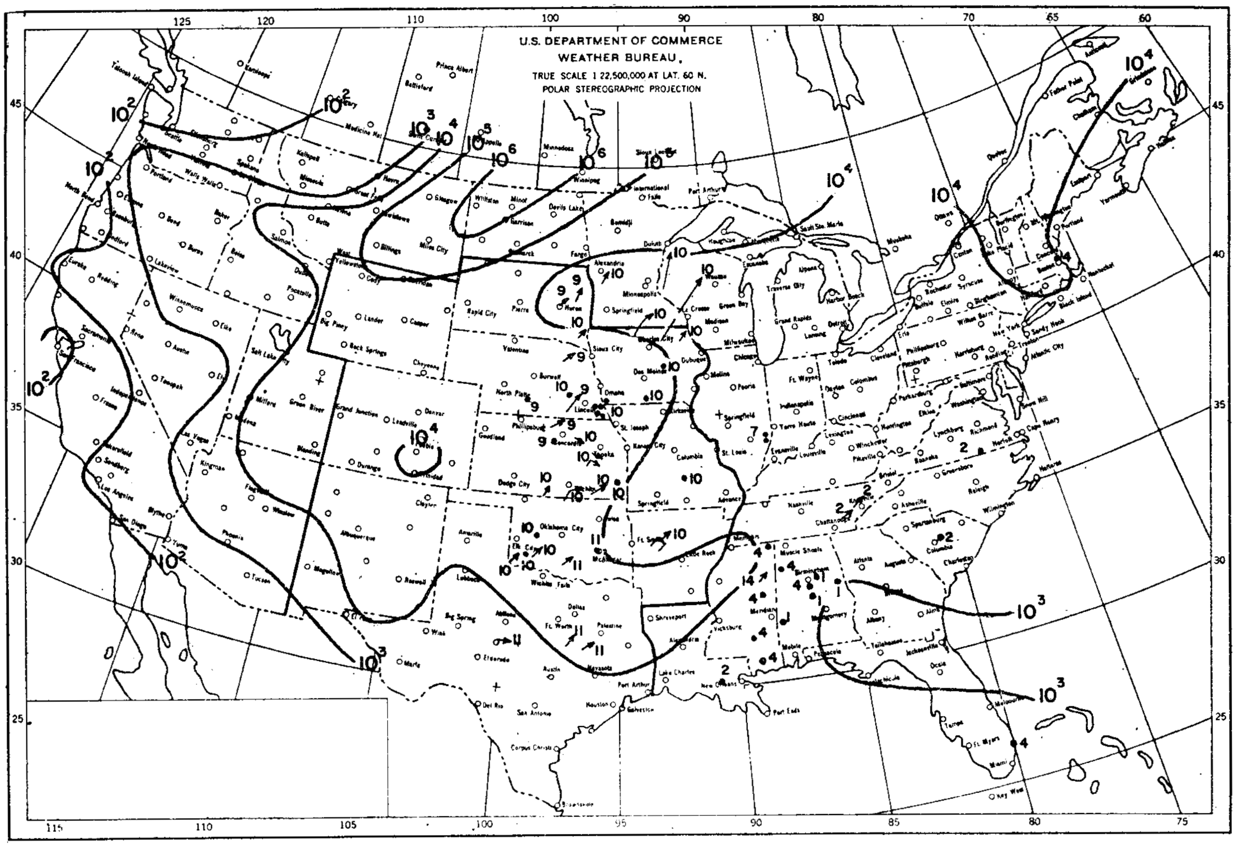

FIGURE 11.—Tornado tracks for May 1–15, 1953 (numbers indicate date) and isolines of radioactive fallout labeled in arbitrary units. A dot indicates a track too short to depict.

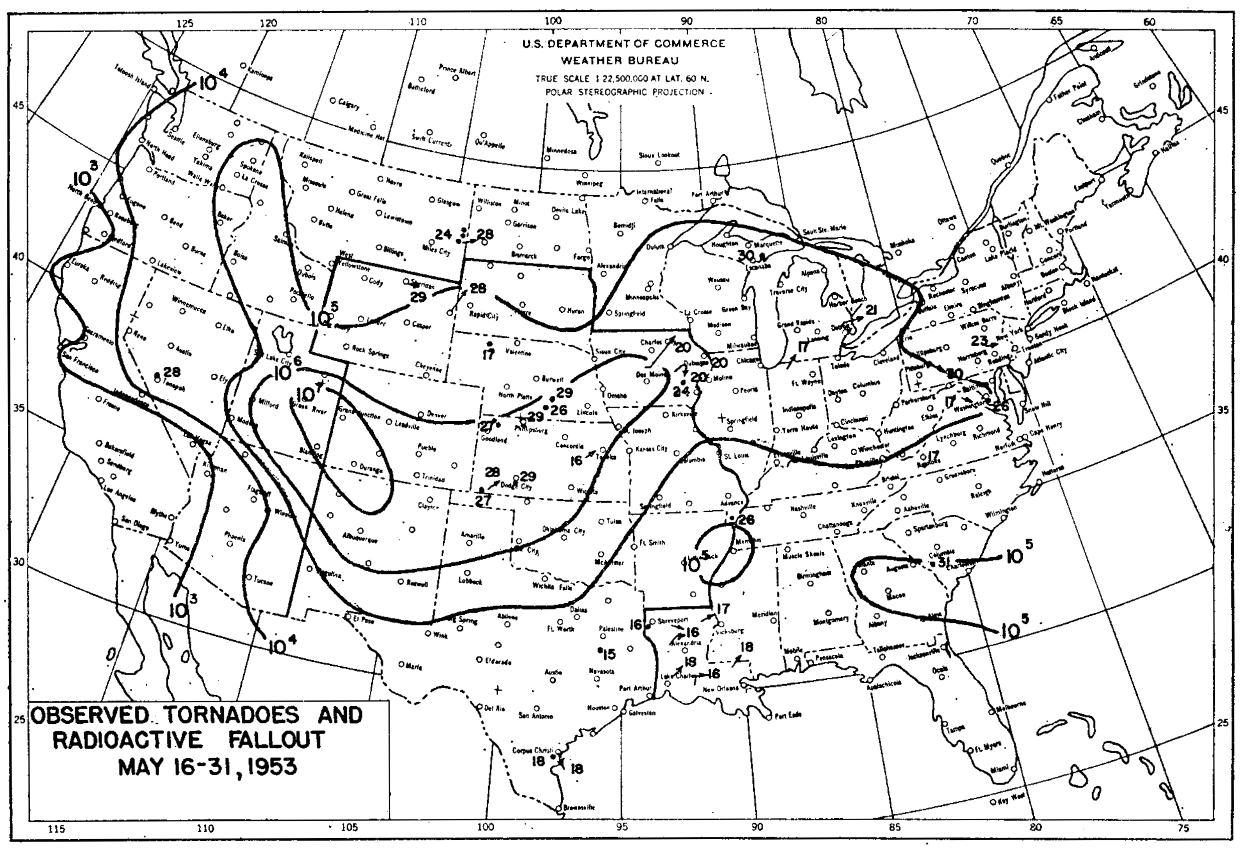

FIGURE 12.—Tornado tracks for May 16–31, 1953, and isolines of radioactive fallout in arbitrary units.

pronounced increase in the amount of fission products in the areas in which the tornadoes occurred. The data for 1954 are provisional and some corrections are to be expected in the official records.

The above data are summarized in figure 9 which shows a comparison of the seasonal distribution of tornadoes in 1951–54 by months with the average value for the period 1921–50. The light line represents the average number of tornadoes for each month expressed as a percentage of the average annual total for the base years 1921–50. The heavy line gives the distribution for each month since 1950, expressed as a percentage of the annual total. The 1954 tornado data were brought into this scheme by assuming that the ratio of the number of tornadoes in the first 8 months of 1954 to the total for the year, would be the same as the average number in the first 8 months to the average annual total in the base years 1921–50. The vertical bars indicate the periods during which atomic tests were conducted. These are summarized in table 3. Each month is regarded as a bomb month if any bombs were exploded during the month or during the last 3 weeks of the previous month.

TABLE 3.—*Departure from the normal seasonal distribution of tornadoes in months with nuclear explosions*

	Nevada bombs	All bombs 1951–53	All bombs 1951–August 1954
Number of months above normal tornado frequency	4	6	7
Number of months below normal tornado frequency	6	9	11
Accumulated percent above normal	12	18	22
Accumulated percent below normal	22	36	46

Actually, the amount of data involved in this table is too small to permit the formation of any reliable conclusions or to justify any test of significance. However, the evidence presented indicates that atomic explosions may have a tendency to inhibit the formation of tornadoes, and that the effect is greatest when the bombs are farthest away. The data certainly do not support the theory that atomic explosions cause tornadoes.

GEOGRAPHICAL DISTRIBUTION OF TORNADOES AND ATOMIC BOMB DEBRIS

If one could assume that the improvement in the reporting system has been about the same all over the country, a similar study could be based on the geographical distribution of tornadoes. However, the effort to improve the completeness of the reporting system between 1950–53 was concentrated in those regions in which tornadoes are most common, and this coincides reasonably well with the regions most frequently crossed by the atomic clouds from Nevada. Thus, one should expect an increase in the relative number of tornadoes reported from these regions irrespective of any effects from the atomic bomb. Although the sparseness of the data and the known lack of uniformity in the records from different States prevent an objective investigation of this effect, some information can be obtained by considering figures 10–12. Figure 10 shows the location and track of all tornadoes reported in May from 1916 to 1950. Figures 11 and 12 give the location of all tornadoes reported in the first and last halves of May 1953. The isolines give the relative cumulative amount of radioactive fallout in arbitrary units recorded by the Weather Bureau network during the period of the maps. In spite of the increased coverage of tornado occurrences due to the press clipping service, no tendency for a relative increase in tornado frequency in those areas most affected by the bomb debris can be found in these figures.

Daily maps of tornado locations have been compared with maps showing the movement of atomic debris for all atomic explosions of the past three years. These maps do not indicate any correlation between the location of tornadoes and the distribution of atomic debris.

SUMMARY

There has been a great increase in the reported frequency of tornadoes in the United States during the past few years. A study of the distribution of reported tornadoes indicates that the reports have been incomplete prior to 1950 and may still be incomplete. However, considerable effort has been spent in the past few years to improve the completeness of these reports, and much of the trend toward an increase in the number of reported tornadoes is due to this effort.

A study of the distribution of tornadoes and atomic explosions in time does not indicate any tendency for a relative increase in tornadoes during periods of atomic explosions. Furthermore, a study of the geographical distribution of tornadoes and the radioactive debris from an atomic explosion does not indicate any tendency for a relative increase in tornado frequency in the regions most affected by the atomic debris.

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